Spectrum Requirements for the Future Development of IMT-2000 and Systems Beyond IMT-2000

Hyun-Goo Yoon, Woo-Ghee Chung, Han-Shin Jo, Jaewoo Lim, Jong-Gwan Yook, and Han-Kyu Park

Abstract: **In this paper, the algorithm of a methodology for the calculation of spectrum requirements was implemented. As well, the influence of traffic distribution ratio among radio access technology groups, spectral efficiency, and flexible spectrum usage (FSU) margin was analyzed in terms of the spectrum requirements, with a view toward for future development of international mobile telecommunication (IMT)-2000 and systems beyond IMT-2000. The calculated spectrum requirement in the maximum spectral efficiency case is reduced by approximately 40% compared to a minimum spectral efficiency case. The effect of the distribution ratio on the required spectrum is smaller than the effect of the spectral efficiency. As the flexible spectrum usage margin increases by 1.0 dB, the total spectrum requirement decreases by 0.9 dB. The required spectrum for the market input parameter, $\rho = 0.5$ is 801.63 MHz, while the required spectrum for $\rho = 1.0$ is 6295.4 MHz. This is equivalent to an increase of 785.32%.**

Index Terms: **Flexible spectrum usage, international mobile telecommunication (IMT)-2000, spectral efficiency, spectrum requirements, systems beyond IMT-2000.**

I. INTRODUCTION

The design objective of next generation mobile communication systems is to support a peak bit rate of up to 100 Mbps with high mobility and up to 1 Gbps with low mobility. The international telecommunication union (ITU) has become involved with the spectrum requirement estimations for next generation mobile communication services in order to meet the above requirements in preparation for the world radiocommunication conference in 2007 (WRC-07). Moreover, ITU will be tasked with producing updated reports on the market and radio aspect analysis for the future development of international mobile telecommunication (IMT)-2000 as well as systems beyond IMT-2000.

In the past, estimations of the spectrum requirements of wireless applications have been considered as a framework focusing on a single system and market scenario. With the advent of a convergence of mobile and fixed telecommunication and multi-network environments as well, supporting attributes like seamless inter-working between different complementary access systems, as described in ITU-R Recommendation M.1390 [1] and ITU-R Recommendation M.1645 [2], the application of such simple approaches is no longer feasible.

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The methodology in ITU-R M.1390 was based on 2G and IMT-2000 technology networks. For this methodology, the model of service delivery is a voice-based traffic architecture including a short message service with some higher data rate services that are characterized by a simple peak-traffic model. An estimate of the spectrum required to carry the projected traffic in the years 2005 and 2010 was developed in ITU-R Report M.2023 [3] using ITU-R Recommendation M.1390. As indicated in ITU-R Recommendation M.1645, it is predicted that the majority of the future traffic will change from speech-oriented communications to multimedia communications. The role of Internet protocol (IP) based traffic will be dominant in the future. Due to this, networks and systems will be designed with the economic transfer of packet data as a top priority.

The methodology in ITU-R Recommendation M.1390 treats each environment and service independently, such that peak traffic for each service within each environment is simply summed together in order to obtain the total traffic volume. ITU-R Recommendation M.1390 could not take into account the fact that some services are interrelated; therefore, the traffic statistics for multiple services had to be combined, at least in some cases.

For an estimation of frequency requirements, therefore, ITU has developed a new spectrum calculation methodology that allows for the consideration of spatial and temporal correlations among telecommunication services, taking account market requirements and network deployment scenarios. Moreover, it was also deemed important to analyze the effects of market-related as well as technology related input parameters on the new methodology for spectrum requirement calculations.

In this paper, the algorithm of a methodology for the calculation of spectrum requirements was implemented. As well, the influence of traffic distribution ratio among radio access technology groups, spectral efficiency, and FSU margin was analyzed in terms of the spectrum requirements, with a view toward for future development of IMT-2000 and systems beyond IMT-2000.

This paper is organized as follows. Section II presents an overview of the spectrum calculation methodology. Section III provides an accounting of input parameters that have much influence on the spectrum requirement calculation and simulation results. Finally, concluding remarks and future directions are presented in Section IV.

II. SPECTRUM CALCULATION METHODOLOGY

The new methodology for spectrum requirement calculations is designed to accommodate a wide variety of applications. The fundamentals for all considerations concerning IMT-2000 networks are the market expectations for wireless communications services in 2010, 2015, and 2020, all of which can be found in ITU-R Report M.[IMT.MARKET]. The key issue in

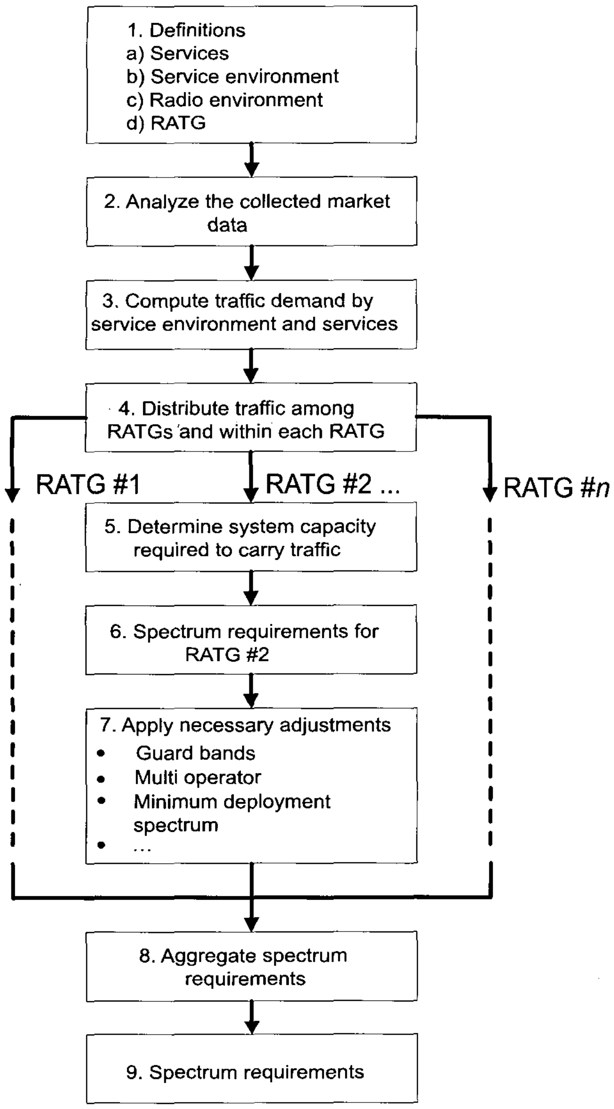

Fig. 1. Flow chart for a generic spectrum calculation methodology.

this respect has to do with the forecast of required communication capacities for uplink and downlink operations of mobile users within IMT-2000 as well as for systems beyond IMT-2000. The methodology takes a technology-neutral approach concerning the technical studies of radio access techniques in it. In addition, this methodology uses the classification of radio access technique groups (RATG) presented in ITU-R Report M.[IMT.RAD_ASPECTS]. The spectrum calculation methodology requires technical parameters as input into the spectrum calculations in order to characterize the different RATGs. With the RATG approach, the technical considerations for the spectrum estimation can easily be conducted without referring to the detailed specifications of radio interfaces both of existing and future mobile systems. The technical considerations include the RATG definitions and the radio parameters associated with the RATGs, which are used at different steps of the methodology. These radio technology aspects and values for the radio parameters, such as spectral efficiency, have been considered and are described in ITU-R Report M.[IMT.RAD_ASPECTS]. The generic flow chart for the calculation methodology is shown in

Table 1. Service categorization.

ST \ TC	Conversational	Streaming	Interactive	Background
Super high multimedia	SC1	SC6	SC11	SC16
High multi-media	SC2	SC7	SC12	SC17
Medium multimedia	SC3	SC8	SC13	SC18
Low rate data & low multi-media	SC4	SC9	SC14	SC19
Very low rate data	SC5	SC10	SC15	SC20

Table 2. The identification of service environments.

Service usage pattern \ Teledensity	Dense urban	Suburban	Rural
Home	SE1	SE4	SE6
Office	SE2	SE5	
Public area	SE3		

Fig. 1 [4].

A. Definitions

First, all necessary categorizations and associated-input parameters for the spectrum calculation methodology are defined. A service category (SC) is a service type (ST) with an associated traffic class (TC) as shown in Table 1. Service environments (SE) are defined as a combination of the service usage pattern and teledensity. Table 2 shows the identification of service environment. Radio environments (RE) are defined to reflect different types of wave propagation phenomena. Typical radio environments are macro cells, micro cells, pico cell, and hot spot areas. RAT and RATGs are also defined in this step. The RATGs suggested by ITU [4] are the following:

- RATG #1: Pre-IMT systems and IMT-2000 and its enhancements.
- RATG #2: System beyond IMT-2000.
- RATG #3: Existing radio LANs and their enhancements.
- RATG #4: Digital mobile broadcasting systems and their enhancements.

B. Market Data Analysis

This step is to analyze the market data, which can be obtained from ITU-R Report M.[IMT.MARKET]. The market data can be collected with the use of the questionnaires. The collected market data should be categorized and calculated in order to obtain the market attributes.

C. Traffic Computation

Step 3 is the computation of the traffic load of different service categories for different service environments, and at different time intervals. This is necessary due to the time-varying and regionally varying natures of the traffic.

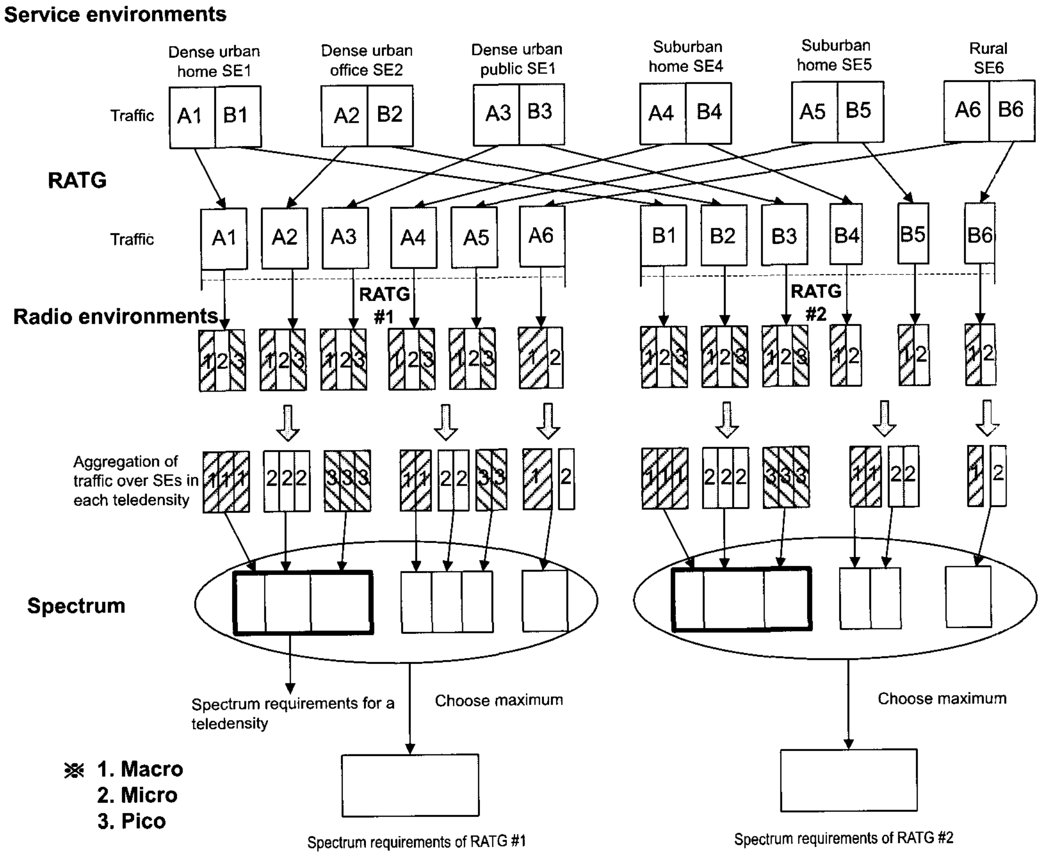

Fig. 2. Traffic distributions among service environments, RATGs, and radio environments.

D. Traffic Distribution

The traffic obtained in the previous step will be distributed to that possible RATs and radio environments. Fig. 2 depicts the traffic distribution process. Mathematically, this can be calculated by multiplying the traffic obtained in Step 3 to the distribution ratio $\xi_{m,n,rat,p}$, which represents distribution ratio for service category *n* for RAT group *rat* in service environment *m* and radio environment *p*.

E. System Capacity

In this step, the required system capacity is determined. The required system capacity must be calculated separately for the uplink and the downlink. For circuit-switched services, the required capacity is calculated by a multidimensional Erlang-B formula [5], while for packed-switched services the required capacity is calculated using the queuing theory [6]. Equation (1) shows that separately calculated capacity requirements must be combined.

$$\begin{aligned} \mathbf{C}_{rat,p,ps} &= \mathbf{C}_{rat,p,ps,UL} + \mathbf{C}_{rat,p,ps,DL} \\ \mathbf{C}_{rat,p,cs} &= \mathbf{C}_{rat,p,cs,UL} + \mathbf{C}_{rat,p,cs,DL} \end{aligned} \tag{1}$$

where the subscripts *ps* and *cs* are the packet switching and circuit switching, respectively, and *UL* and *DL* represent the uplink and downlink, respectively. Following this, the capacity requirement for packed switching and circuit switching is calculated as

$$\mathbf{C}_{rat,p} = \mathbf{C}_{rat,p,ps} + \mathbf{C}_{rat,p,cs}. \tag{2}$$

F. Spectrum Requirement for Each RATG

In Step 5, the spectrum requirements for each RAT group is calculated. The spectrum requirement for RAT group *rat* in service environment *m* and radio environment *p* is obtained from

$$\mathbf{f}_{m,rat,p} = \frac{\mathbf{c}_{m,rat,p}}{\eta_{m,rat,p}}, \tag{3}$$

where $\mathbf{f}_{m,rat,p}$ denotes the m-th row vector of the spectrum requirement matrix $\mathbf{F}_{m,rat,p}$.

G. Necessary Adjustment

Adjustments are made taking into account the minimum spectrum requirements for a network deployment, the necessary guard bands, and the impact of the number of operators.

H. Aggregation of Spectrum Requirements

Finally, the spectrum requirements are aggregated over time intervals and teledensity environments. It is important to note that the maximum value of spectrum requirements in time and teledensity was selected due to the spectrum requirement time dependency. With an FSU possibility between RAT groups, the aggregate spectrum demand for the RAT groups that support FSU can be calculated in this step. Without FSU, the spectrum need for the RATG *rat* in teledensity *d* is the maximum over time

$$F_{d,rat} = \max_t (F_{d,t,rat}). \tag{4}$$

Table 3. Simulation parameters.

Parameter	Value
Market input parameter ρ	$0.5 \sim 1.0$
Service category	$1 \sim 10$ (circuit-switching) $11 \sim 20$ (packet-switching)
Service environment	$1 \sim 6$
Distribution ratio	RATG #1 : r % RATG #2 : (100–r) %
Radio environment	$1 \sim 4$
Mean packet size [byte]	1500 (SC11 $\sim$ SC15) 540 (SC16 $\sim$ SC20)
2nd moment of packet size [byte^2]	4500000 (SC11 $\sim$ SC15) 583200 (SC16 $\sim$ SC20)
Mean packet delay [sec]	0.04 (SC11 $\sim$ SC15) 0.4 (SC16 $\sim$ SC20)
Blocking probability	0.01 (SC1 $\sim$ SC10)

With an FSU possibility between RATGs, the aggregate spectrum demand for the RATGs that support FSU is calculated by summing the spectrum demands of each RAT, independently for each teledensity.

$$F_{d,rat} = FSU_{marg} \sum_{rat \in \{FSU\ RATs\}} F_{d,t,rat}. \quad (5)$$

III. SPECTRUM REQUIREMENTS

In this section, the influence of the input parameters of the spectral efficiency, traffic distribution ratio among radio access technology groups, and flexible spectrum usage margin on the spectrum requirement calculation is analyzed. The above parameters are those that may greatly influence the spectrum requirements.

A. Simulation Parameters

The input parameters for the spectrum requirement calculation can be categorized into market-related parameters and technology-related parameters. Market-related parameters can be obtained from ITU-R Report M.[IMT.MARKET]. The market-related parameters are based on the data collected from the questionnaires. In the simulation, the market data given in [4] was utilized; however, the market input parameter ρ shown in (6) was used to control the range of market values,

$$\rho = \%\ \text{of maximum market value}. \quad (6)$$

For each RATG, the area spectral efficiency matrix needs to be estimated. The area spectral efficiency of each RATG in each radio environment can be estimated using average spectrum efficiency, which is determined taking after into account the propagation characteristics, interference considerations, and typical deployment scenarios, as well as the technical requirements for the technical characteristics. In RATG #1, pre-IMT systems and IMT-2000 and its enhancements are included, and in RATG #2, system beyond IMT-2000 (e.g., new mobile access and new nomadic/local area wireless access) are included. RATG #2 is more efficient than RATG #1 in terms of the use of spectrum resources; therefore, the traffic distribution ratio between RATG #1 and RATG #2 is an important parameter in spectrum requirement calculation. When the time dependency of the spectrum requirements is considered, the FSU possibility is typically used. From (5), the spectrum requirement with an FSU possibility is inversely proportional to the FSU margin. The general parameters used in the simulation are shown in Table 3. Traffic for SC1 to SC10 is circuit-switched, while traffic for SC11 to SC20 is packet-switched. If the traffic distribution ratio for RATG #1 is r%, and that for RATG #2 is (100–r)%, then the blocking probability for circuit-switched traffic is set to 0.01.

Table 4. Spectral efficiency scenarios.

Scenario	RATG	Spectral efficiency			
		RE1	RE2	RE3	RE4
1	1	1	0.7	0.4	0.4
	2	10	6	5	3
2	1	1	0.7	0.4	0.4
	2	7.5	4.5	3.5	2.5
3	1	1	0.7	0.4	0.4
	2	5	3	2	2

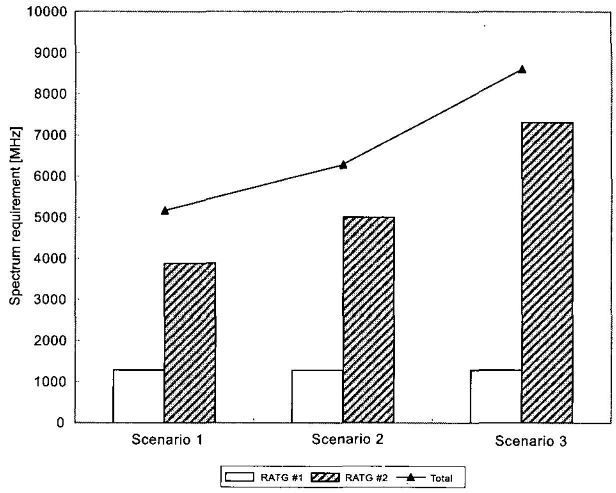

Fig. 3. The required spectrum per RATG for Scenarios 1, 2, and 3.

B. Simulation Results

The algorithm of spectrum requirement methodology was implemented using the MATLAB software. As shown in the previous section, effects of the input parameters in the methodology on the spectrum requirements are simulated. Fig. 3 presents required spectrum per RATG for Scenarios 1, 2, and 3, which are summarized in Table 4, where the distribution ratio for RATG #1 is 20%, the FSU margin is set to unity, and ρ =1.0. The necessary adjustments in case of multi-operator scenarios or guard bands are not taken into account here. The influence of the higher spectral efficiency value is visible in Scenario 1. Compared to the minimum spectral efficiency (e.g. Scenario 3), the required spectrum in Scenario 1 is reduced by approximately 40%. The required spectrum according to the distribution ratios is shown in Fig. 4. It is clear that the distribution ratio has less effect on required spectrum than spectral efficiency. Fig. 5 depicts the influence of the FSU margin on the spectrum requirement. Because RATG #1 does not support FSU, the FSU margin

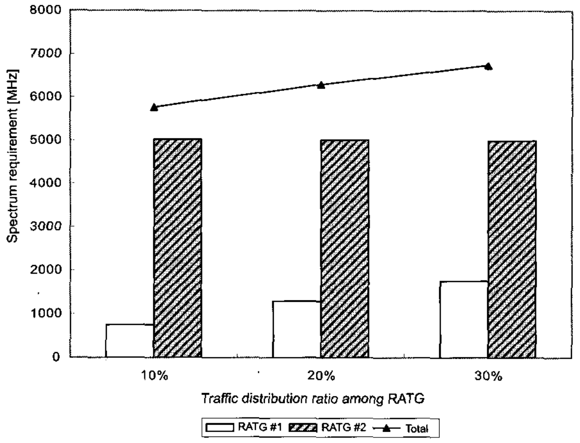

Fig. 4. The required spectrum according to distribution ratio.

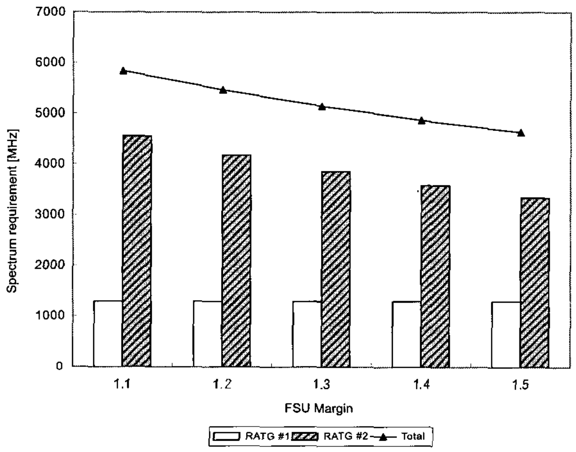

Fig. 5. The required spectrum according to the FSU margin.

is applied to the spectrum requirement calculation of RATG #2. As the FSU margin increases by 1.0 dB, the total spectrum requirement is decreased by 0.9 dB.

Fig. 6 presents the spectrum requirement calculation results according to the market input parameter ρ. The required spectrum for market input parameter $\rho = 0.5$ is 801.63 MHz, and the required spectrum for $\rho = 1.0$ is 6295.4 MHz. This shows an increase of 785.32%. It can be concluded that the market input parameter ρ is an essential input in order to make an estimate of the spectrum.

IV. CONCLUSION

In this paper, the algorithm of a methodology for the calculation of spectrum requirements was implemented. As well, the influence of traffic distribution ratio among radio access technology groups, spectral efficiency, and FSU margin was analyzed in terms of the spectrum requirements, with a view toward for future development of IMT-2000 and systems beyond IMT-2000. Compared to a minimum spectral efficiency case, the required spectrum in a maximum spectral efficiency case is reduced by about 40%. Moreover, the distribution ratio has less of an effect on the required spectrum than spectral efficiency. As the FSU margin increases by 1.0 dB, the total spectrum requirement decreases by 0.9 dB. The required spectrum for the market input parameter $\rho = 0.5$ is 801.63 MHz, while the required spectrum for $\rho = 1.0$ is 6295.4 MHz, showing an increase of 785.32%.

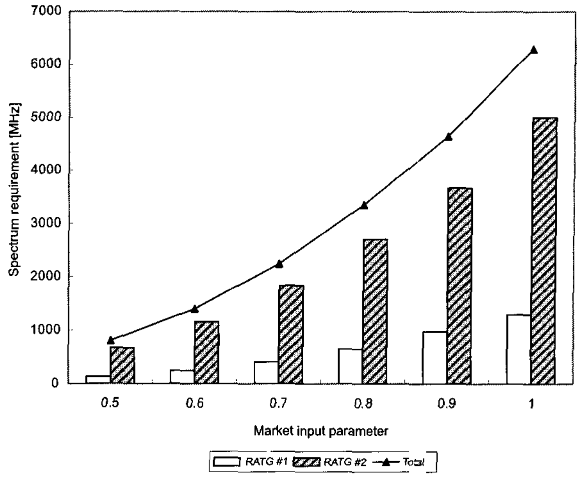

Fig. 6. The required spectrum for the market input parameter ρ.

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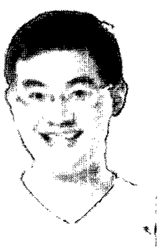

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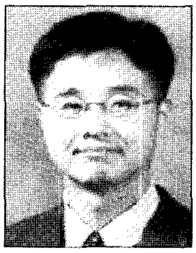

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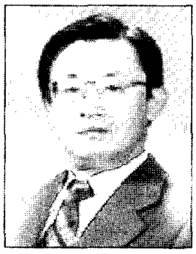

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